E.Kistenev
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Nose cone calorimeter for the PHENIX forward upgrade - specifications

The Nose Cone Calorimeter location in the experiment, its lateral and longitudinal structure are shown in the next few figures included into this paper for completeness. Tables below list "desired" values which are still a subject to considerations. Last two chapters provide for more detailed explanations to the choices made for the most crucial parameters affecting frontend. Major assumption which sets the stage – the same frontend electronics should work for every channel in the calorimeter including those most loaded around the beam pipe.
Another assumption made in this document which needs to be verified is the feasibility of designing and manufacturing the fast preamplifier capable of handling detector capacitances up to 1300 pF (up to 10 silicon pixels in parallel) while keeping the noise at an acceptable level.

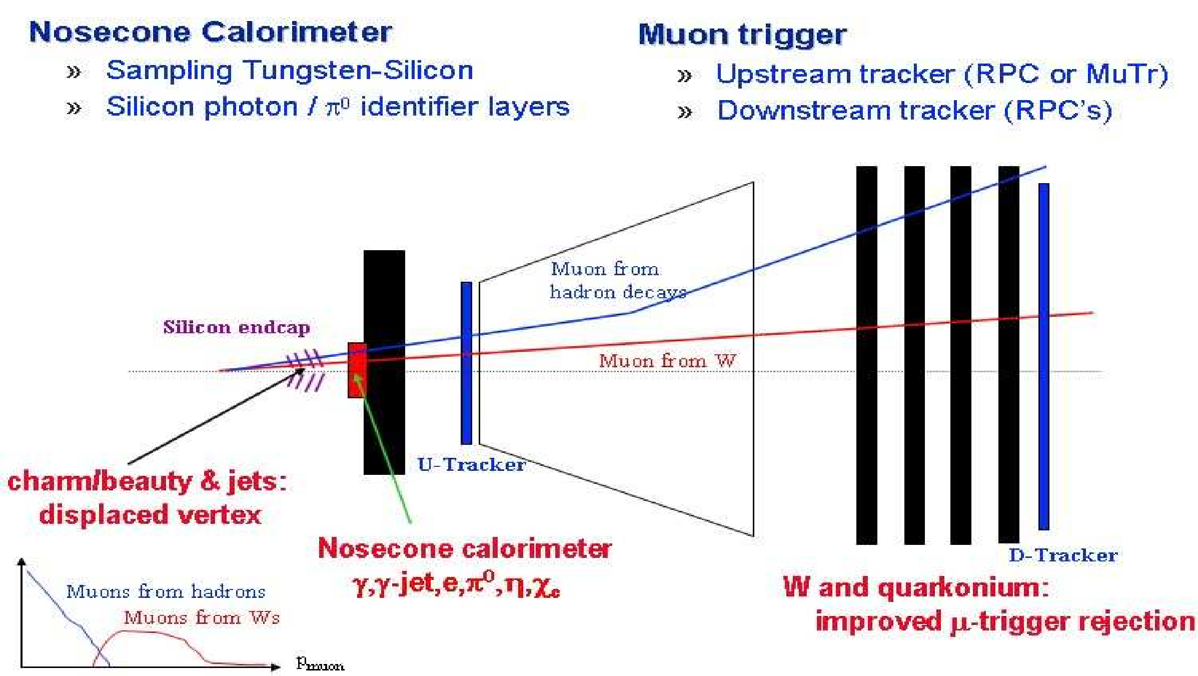


Fig. 1 Upgraded PHENIX Forward Spectrometer

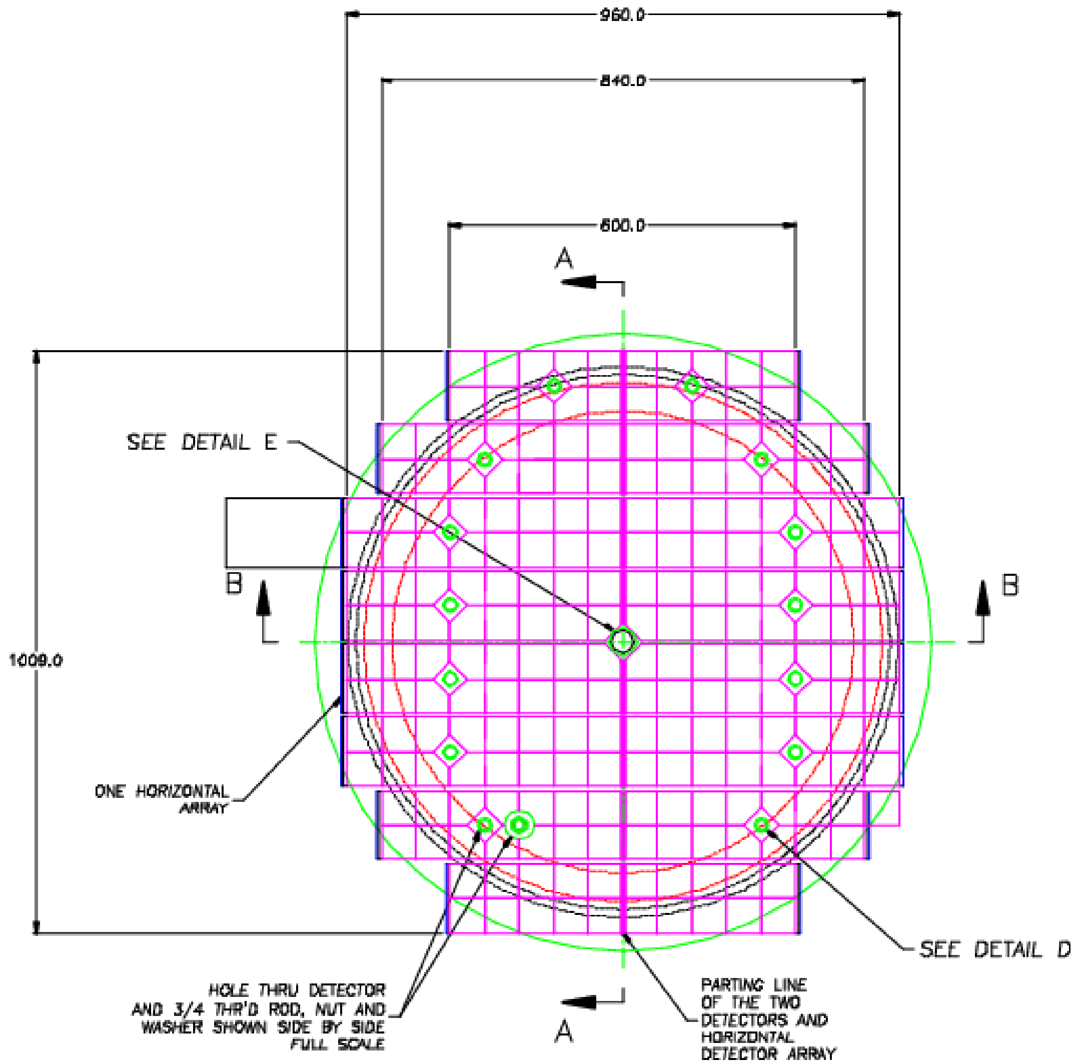


Fig. 2 Lateral structure of the proposed PHENIX Nose Cone Calorimeter

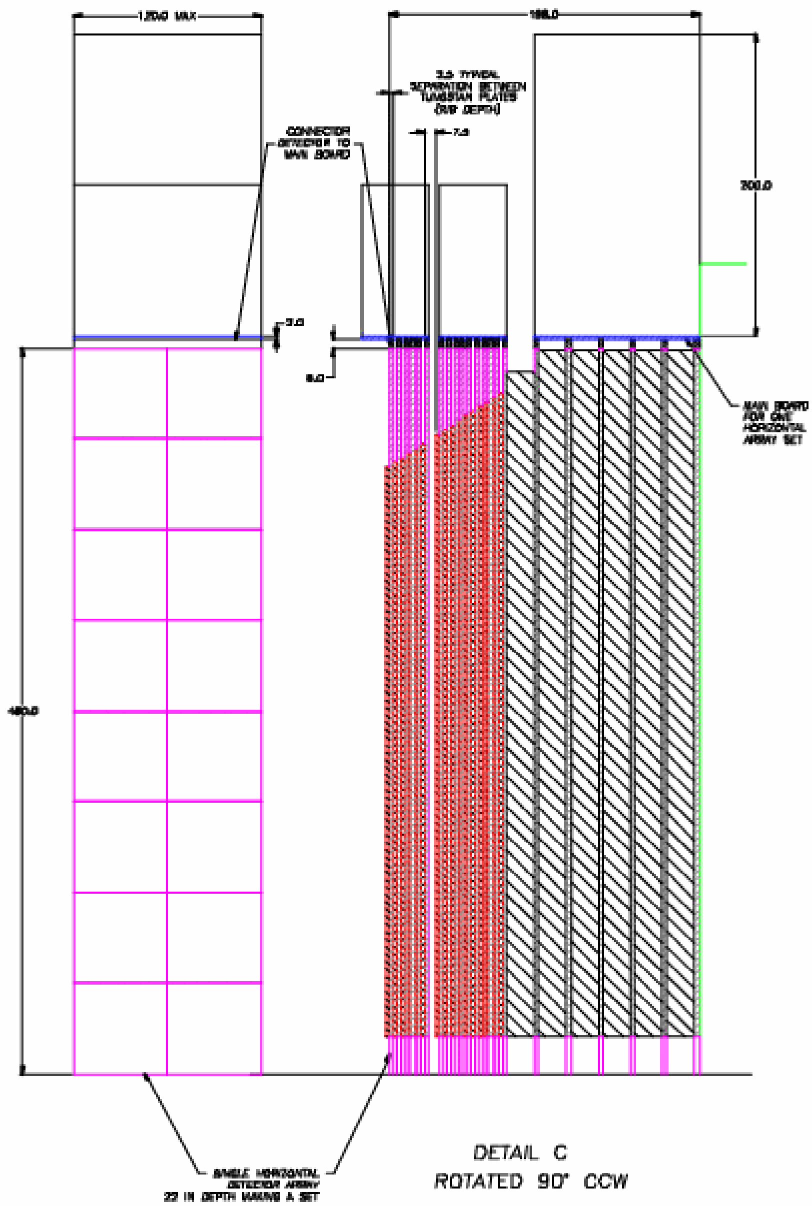


Fig. 3 NCC Longitudinal structure. Lateral structure of the longest readout unit (hadronic section) is also shown. At a time when this picture was made we assumed that all three longitudinal sections will have identical readout layout. This assumption was later reconsidered resulting in reduced lateral coverage in the first two sections.

Global parameters (all numbers for a single NCC)

Calorimeter		
Starts at	40 cm	From collision point
Total depth	20 cm	Along the beam line
Weight (mainly W)		
Silicon sensor	6x6 cm^2	
Silicon wafer thickness	300 mkm	
Sensors total	3776	
Pad size	1.5x1.5 cm^2	
Pad capacitance	78 pF	
Trace capacitance		
EM sections	10-45 pf	
Had sections	10-55 pf	
Dynamic range (energy)	~100 GeV	In a tower. 50 GeV maximum in a single long. comp.
MIP signal in a single Si layer (e)	24k	
MIP signal in a tower (e)	144k-240k	
Dynamic range (MIP's in the tower) MIP_{10}	>1000	MIP signal is summed up over all contributing layers (10 layers max)
Maximum charge in a pulse	40 pC	**~2.1*10^8 e**
Precision (bits)	11 or 12	
Range switching at	1.5 - 3 GeV	
Signal base-to-base time	~ 300 ns	
Spread in the peaking time	~10 ns	Due to the spread in vertex position and differences in the flight path
Shaping time		May need hard clock triggered reset
Maximum charge rate	10^{-6} C/s	

γ–π^0 identifier		
Located at	43 cm	From collision point
Number of layers	2	Orthogonal strips
Silicon sensor	6 x 6 cm^2	
Silicon wafer thickness	300 mkm	
Sensors total	152 x 2	
Strip size	~2 x 60 mm^2	
Strip capacitance	40 pF	
Trace capacitance	10-45 pf	
Total capacitance per channel	50-85 pf	
Readout chip	SVX4	
Dynamic range		
Dynamic range (MIP's)		
Maximum charge in a pulse		

Calorimeter - 1st longitudinal section		
Geometrical total depth	3cm	
Number of sampling layers	6	
Sampling fraction	1.7%	
MIP energy loss	~42 MeV	
MIP energy loss in Silicon	~0.7 MeV	
Diameter	80 cm	
Sensors per layer(6x6 cm2)	152	
Sensors total	912	
Channels of ADC's	2432	
Capacitance(pad+traces)	90-130 pf	
Tower capacitance	540-780 pf	
Tower ENC limit	15 k	

Calorimeter - 2nd longitudinal section		
Geometrical total depth	5cm	
Number of sampling layers	10	
Sampling fraction	1.7%	
MIP energy loss	~69 MeV	
MIP energy loss in Silicon	~1.2 MeV	
Diameter	80 cm	
Sensors per layer (6x6 cm2)	152	
Sensors total	1520	
Channels of ADC's	2432	
Capacitance(pad+traces)	90-130 pf	
Tower capacitance	900-1300 pf	
Tower ENC limit	24 k	

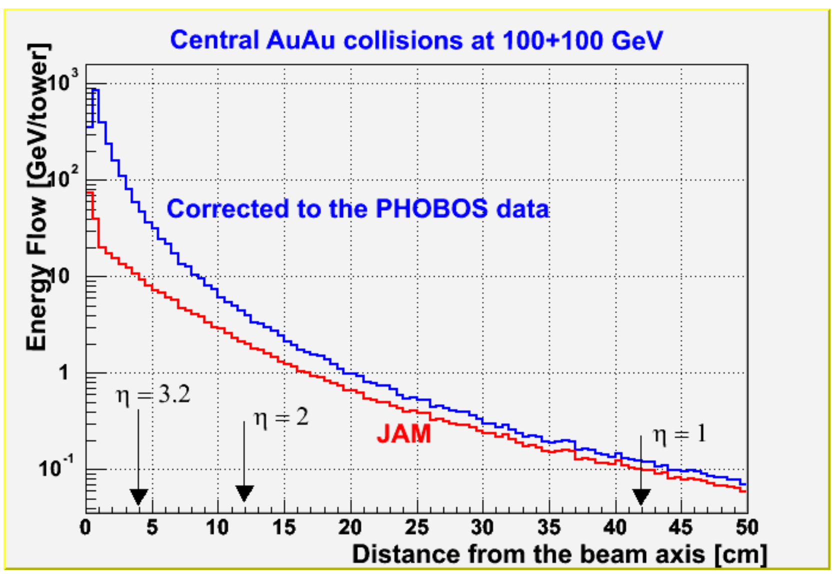
Calorimeter - 3d longitudinal section		
Geometrical total depth	~11cm	
Number of sampling layers	6	
Sampling fraction	0.26%	
MIP energy loss	~270 MeV	
MIP energy loss in Silicon	~0.7 MeV	
Diameter	96 cm	
Sensors per layer (6x6 cm2)	224	
Sensors total	1344	
Channels of ADC's	3584	
Capacitance(pad+traces)	90-150 pf	
Tower capacitance	540-900 pf	
Tower ENC limit	15 k	

Dynamic range

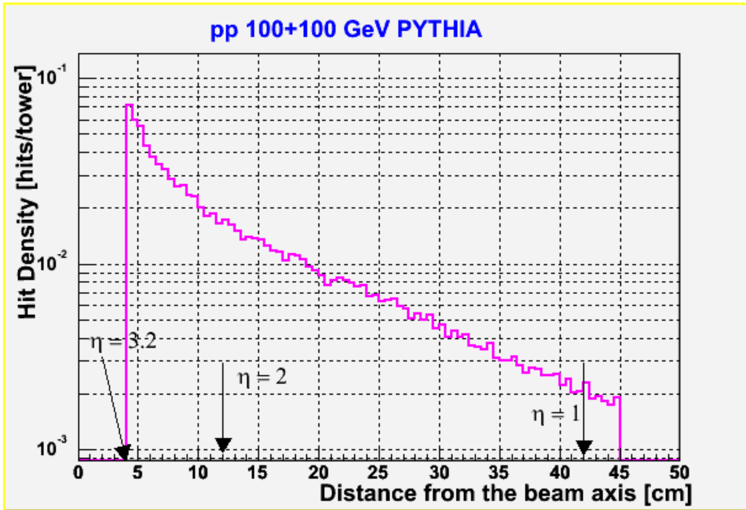
It is commonly assumed for the calorimeters that dynamic range must be set close or below the maximum particle energy allowed by kinematics. In case of forward calorimeter this value is close to the beam momentum and can be safely assumed equal to 100 GeV for AuAu and 250 GeV for pp collisions. In fact 250 GeV is likely to be an overkill, maximum momentum of the electron from the semileptonic decay of the forward produced W boson is certainly a better limit. In what follows we assume the limit to dynamic range set by interaction kinematics equals to 100 GeV.

Uncertainty arises only when we are trying to account for the contribution from underlying event, the latter can be estimated as follows.

We used JAM heavy ion collision simulation program to estimate if underlying event can affect the choice of dynamic range in heavy ion collisions. The corresponding data are presented in the next figure. Given the well known fact that JAM disagrees with the data in many aspects, JAM multiplicity distribution was normalized to the one published by PHOBOS (particle composition and pt spectra agrees with the data within the reason). At a 4 cm radius in the central AuAu collisions the energy in the underlying event is <10 GeV, fluctuations are small and can be neglected compared to our preset limit of 100GeV.



In pp collisions the average energy per tower in minimum bias events is less then 0.1 GeV/event (see next picture, PYTHIA simulation) and can be neglected compared to our initial estimate (beam momentum) for the upper limit to dynamic range.



The estimates of the energy due to soft component depend on the cms energy only logarithmically, colliding 250 GeV/c beams will result in less in ~40% increase to the pp values estimated at 100 GeV/c.
While further detailed simulation is certainly required for now we can assume that 50% of energy (~50 GeV max) is deposited in the second section of calorimeter which sets the ultimate limit to the charge in a single pulse. For (2.5 mm W / 0.3 mm Si) cell which samples ~ 1.7% of the deposited energy or ~0.85 GeV **the maximum total charge collected from 10 layers of silicon connected in parallel to a common preamplifier input is equal to ~$2.1*10^8$ e (~40 pC) or ~x 1000 MIP_{10} signal (summed over 10 layers).** For 12 bit ADC's the least count is equal to 125 MeV or ~5 10^4 electrons to be compared to $2.4x10^5$ electrons in the MIP_{10} peak what is likely to be unsatisfactory (not to forget that our estimates are for the towers next to the beam line, typical energies at the outer calorimeter radius are much lower). **The solution is the one implemented by Trieste group in their most recent R&D project – it allows for dynamic switching of the binning for the signals above certain threshold to realize an effective 16 bit range. A x16 change in the bin width for the signals above ~1.5 GeV allows to reach 16 bits range with 12 bits precision everywhere.**
It is unclear if flag indicating gain selection must be counted as an extra bit in the bit counting, if answer is positive we may consider reducing the bit range to 11/15 what is still satisfactory even for MIP signal measurements.

Rate or integrated charge

The next question is a charge rate per unit time which must be well known and understood to avoid base line shifts leading to the loss of dynamic range. Once again we'll use calorimeter area close to the beam pipe to set the limit which is now entirely due to the very high interaction rate expected in pp-collisions at 500 GeV. RHIC II predictions for the average number of inelastic pp-collisions per crossing are in the vicinity of 1.5. Using the data shown in the very last figure (~0.08 GeV/tower/min. bias event) the expected energy rate per unit time in the most exposed towers of the central calorimeter compartment equals to

$$E = 5 \text{ x } 10^7 \text{ x } 0.08 \text{ x} 0.5 \sim 2\ 10^6 \text{ GeV/s}$$

Converting total energy into sampled energy and charge is trivial

$$Q = 2\ 10^6 \text{ x } 0.017 / 4\ 10^{-9} = 8\ 10^{12} \text{ e/s} = 10^{-6} \text{ C/s.}$$

In fact using the value of the energy flow per unit time one can try to "guestimate" the radiation load in silicon close to beam pipe. A canonical number for calorimeters is 3 particles per GeV of deposited energy at a shower max position. Applying this conversion factor we end up with an order of magnitute estimate for the maximum flux of charged particles crossing the silicon layers in the second compartment

$$N_{max} = 2\ 10^6 \text{ x } 3 / 2.25 \sim 3\ 10^6 \text{ 1/s/cm}^2$$

Except if beam related background is much higher then collision related background it will take many years of running to see the radiation effects in this calorimeter.

Hit rate

PYTHIA simulation was also used to estimate hit multiplicity and tower occupancy in the area close to the beam pipe in pp-collisions. According to this simulation the probability for tower to receive a direct hit in the minimum bias event is ~3% and exponentially drops with radius. We are "helped" by the fact that our calorimeter totally absorbs only electromagnetic showers what effectively limits the number of towers fired by the shower (deposition above 2% of the total shower energy) to 4 towers resulting in nearly 10% occupancy in the very central part of the calorimeter. Unless proven otherwise the 10% occupancy sets an ~ 300ns limit for base-to-base signal pulse length after shaping (probably can be extended to 500 ns).